

Preparations of the TAMU-ORNL BaF₂ array

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The TAMU-ORNL BaF₂ Array is comprised of 130 detector modules. Each has a hexagonal prism crystal of BaF₂ 20 cm long and 6.5 cm from face to face. The crystal is coupled directly to a UV-sensitive photomultiplier tube (PMT). In preparation for upcoming experiments, the coupling between each crystal and its PMT has been remade. For much of the array, the energy resolution has been checked. The impact of the new coupling on the particle discrimination and the timing has been investigated on a few select detectors.

Previously, the coupling was made with viscous silicone oil (1×10^5 centistokes), which is translucent to UV light near 200nm. This transmission is important since the fast component of the scintillation light is primarily at 210nm. Each crystal and PMT is wrapped in polytetrafluoroethylene (Teflon) tape to reflect light until it reaches the photocathode. Black electrical tape is then used to completely exclude external light from the detector. Over time, the silicone oil oozes from the coupling and wets the Teflon tape, turning it translucent and thus decreasing the light collection efficiency and therefore the resolution. It was desired to use a coupling that would last longer without sacrificing resolution and without losing the ability to decouple the detectors as needed (e.g. for PMT replacement).

Room-Temperature Vulcanization (RTV) silicone rubber was chosen as the coupling material. It can be made into a very thin layer and has optical transmission near 200nm, though in this region the transmission decreases rapidly with RTV thickness. After cleaning the crystal and PMT faces with anhydrous methanol, a small dab (approximately 0.3mL) of vacuum-degassed RTV (Momentive 615A+B) is applied to the PMT quartz window and allowed to rest a few minutes until flat and smooth. Any stray bubbles are removed, filled in with RTV and again allowed to rest. The PMT is inverted and mated with the crystal face; care is taken not to introduce bubbles. A jig is used to secure the PMT in place while the RTV sets for 5 days, after which time the Teflon tape and electrical tape are applied followed by the mu-metal shield and tension sling to complete assembly. The coupling of the crystal to PMT, which has a surface area of nearly 20cm², can be safely broken by applying a heating tape at 90°C for one hour to the coupling and then twisting carefully. Decoupling is not trivial, but is possible to do without harming the brittle crystal.

Fig. 1 shows data obtained with a BaF₂ detector freshly coupled with RTV. Gamma sources provided peaks at 1173keV and 1332keV (⁶⁰Co) and 662keV (¹³⁷Cs). Alpha decay of radium impurities in the detector can also be seen. In the correlation of the fast component of the light output (20ns window around the peak) and the total light output (1.5μs), as seen in Fig. 1, the gamma rays (upper locus) can be distinguished from the charged particles (lower locus). Though the RTV may be attenuating the fast light by some amount [1], the thickness of the RTV layer (which is significantly less than 100μm) does not prevent pulse-shape discrimination. The quality of the neutral and charged band separation is comparable to that achieved with the viscous silicone oil coupling. The projection of the data in Fig. 1 onto the “total” axis is shown in Fig. 2. The lower peak (662keV) has a width (FWHM) of 14.8%.

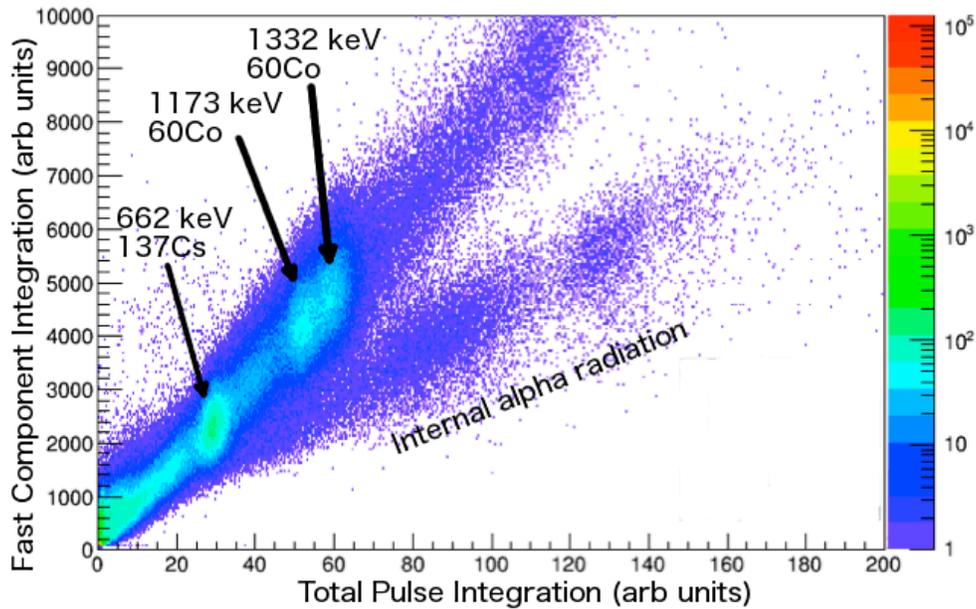


FIG. 1. Fast integral vs total integral for a BaF₂ detector recoupled with RTV. The separation of the gamma line (upper) and alpha line (lower) indicates that the RTV does not significantly attenuate the photons in the fast component.

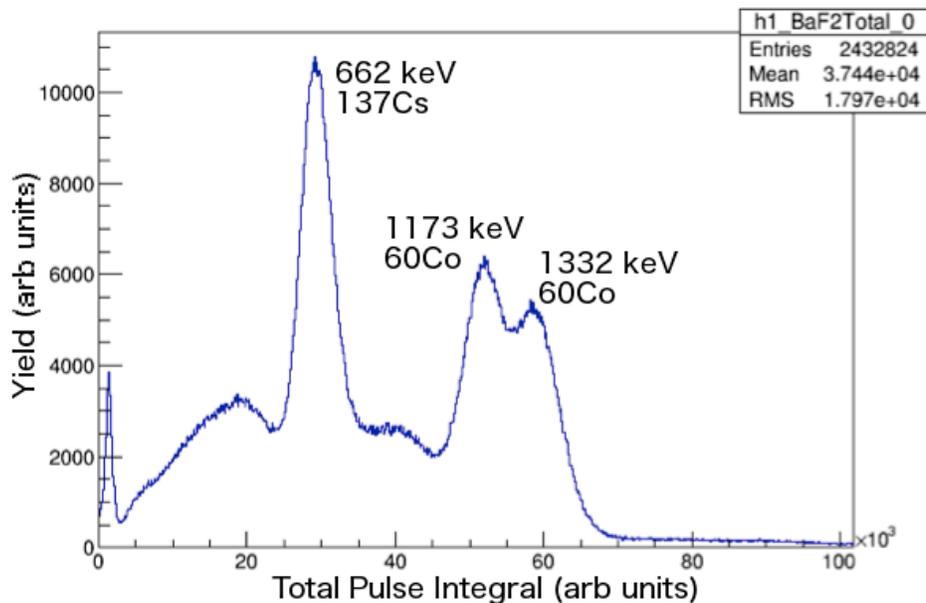


FIG. 2. Total integral after recoupling with RTV. The peaks are obtained using ⁶⁰Co and ¹³⁷Cs sources. The 662 keV peak shows resolution of 14.8%.

The resolutions of several detectors before and after recoupling were measured in the same way. Fig. 3 summarizes the results. Certainly, the resolution with the RTV is not worse than with the silicone oil. For a few detectors, the gamma sources were placed very close to the detector to increase the rate of the gammas of interest relative to the background. This improved the resolution slightly, indicating the

importance of accurate background subtraction. The detector resolutions are generally between 15% and 20%. This is believed to be limited by the age of the PMTs. Likely with newer PMTs this could be brought down to 10-15%.

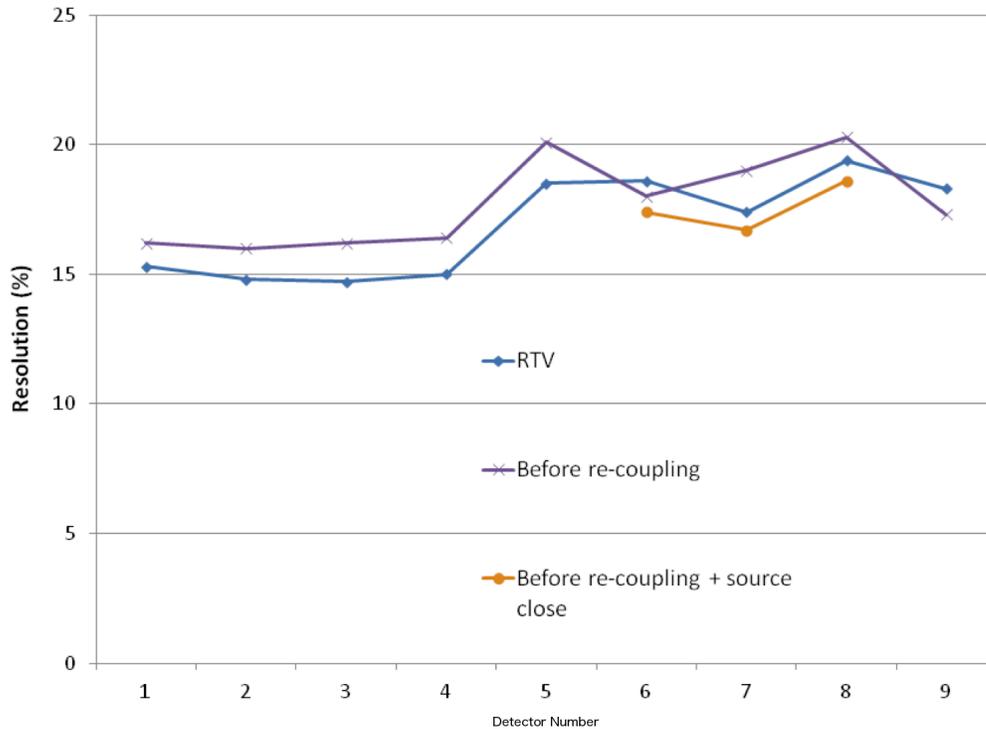


FIG. 3. Resolution of the 662 keV ^{137}Cs peak in nine different detectors before and after recoupling.

Timing resolution is important to discriminate gamma rays from neutrons and from low-energy charged particles. A ^{22}Na source, which produces pairs of photons from positron annihilation, was placed adjacent to two BaF_2 detectors. The anode signals were split and sent not only to flash digitizers (SIS3316) as before but also to discriminators (CAEN-V812) followed by time-to-digital converters (CAEN-V775). The time difference is shown in Fig. 4 with arbitrary offset. The width of the timing peak (FWHM) is 0.9ns, which is sufficient to discriminate high-energy neutrons (even beyond 100 MeV) from gamma rays for a flight path of 100cm. Tennelec TC454 CFDs and Philips 708 leading edge discriminators provided poorer resolutions (both 1.6ns FWHM).

The BaF_2 array is being prepared to serve in two upcoming experiments. One will measure gamma rays in reactions of $^{59}\text{Fe}(d,p)^{60}\text{Fe}$. The neutron capture cross-section is important as a waiting point in s-process nucleosynthesis [2]. The other experiment will measure hard gamma rays produced in n-p Bremsstrahlung, which are predicted to be sensitive to the symmetry energy in the nuclear equation of state [3].

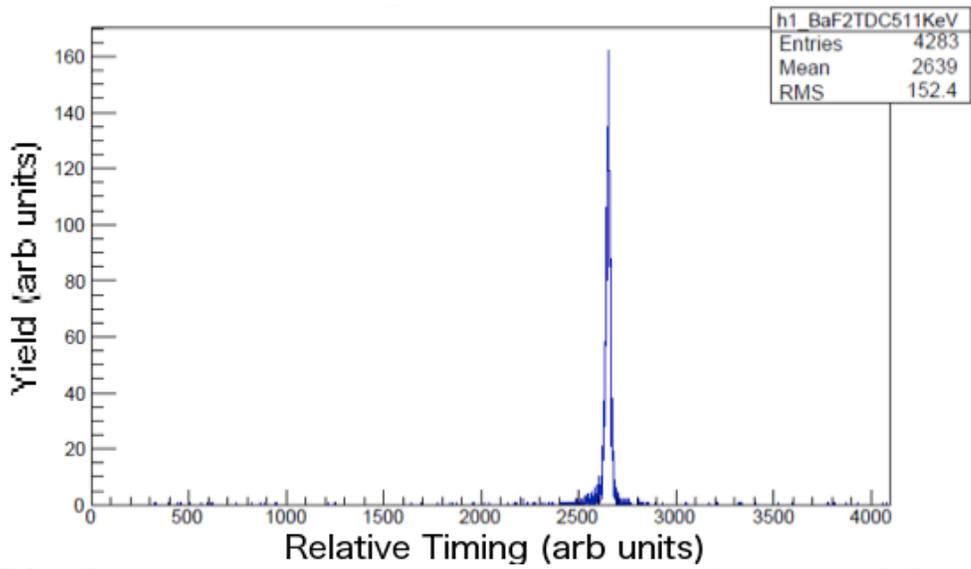


FIG. 4. Time resolution of a pair of positron annihilation photons detected in two BaF₂ modules after recoupling with RTV. The FWHM is 0.9ns. This demonstrates that the RTV does not prevent the fast light from being used for precision timing.

- [1] W. Li and G.M. Huber, J. Inst. **9**, P07012 (2014).
- [2] Uberseder *et al.*, Phys. Rev. Lett. **102**, 151101 (2009).
- [3] Yong *et al.*, Phys. Lett. B **661**, 82 (2008).